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Riparian Vegetation, Natural Succession, and the Challenge of Maintaining Bare Sandbar Nesting Habitat for Least Terns and Piping Plovers

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BACKGROUND AND PROBLEM STATEMENT: This technical note provides a framework for effective (and cost-effective) management of pioneering vegetation on bare riverine sandbars that may provide nesting habitat for federally listed Interior Least Terns (ILT) (*Sternula antillarum*) or Great Plains Piping Plovers (GPPP) (*Charadrius melodus*).

The authors acknowledge that significant costs (and potential consequences) can be associated with vegetation management; the decision to actively manage vegetation on any one river will be made in full consideration of a range of management alternatives in the framework of meeting multiple objectives, many of which may have nothing to do with endangered species (Schultz et al. 2010). This technical note assumes that vegetation removal is at least being considered for an area and provides the basic principles necessary for a vegetation removal program to be successful.

It is also acknowledged that habitat-forming flows are less frequent than they were prior to dam placement on many rivers (Galat and Lipkin 2000; U.S. Fish and Wildlife Service (USFWS) 2003, 2005a; Parham 2007). When sandbar nesting habitat becomes degraded due to advanced vegetation succession (e.g., Johnson 2000) the only alternative to provide regional nesting habitat for the two listed bird species mentioned above may be mechanical sandbar restoration, which is extremely costly and may have undesirable ecological consequences (U.S. Department of Interior (USDOI) 2006, U.S. Army Corps of Engineers (USACE) 2011). Consequently, managers within systems where habitat renewal via flooding is infrequent may want to consider an approach of maximizing the number of years that new bare sandbars remain suitable for nesting. They may also want to consider managing vegetation early in the successional sequence to forestall the loss of depositional areas (which may be in short supply regionally) to late-successional forests that could provide future sandbar nesting habitat after future high-release events. This is a decision that managers will have to make on a case-by-case basis, given the knowledge that they are able to acquire about the frequency of habitat-forming (e.g., vegetation-removing) flows within their system (Sidle et al. 1992, Leslie et al. 2000, USACE 2011).

Ecological restoration programs are sometimes initiated for the exact opposite purpose, to encourage riparian vegetation recruitment. In some instances, this action occurs on the same rivers where maintaining bare sandbar nesting habitat is a condition of incidental take permits within USFWS' Biological Opinions regarding USACE dam operations (USFWS 2003, 2005a, 2005b, 2006). This document is focused on providing bare sandbar nesting habitat (SNH) for birds, and will be useful to managers with this objective. However, those engaged with riparian vegetation restoration are encouraged to become familiar with this issue and collaborate with biologists who are tasked with maintaining bare sandbars for nesting. Such collaboration will reduce potential

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conflicts between restoration programs with potentially conflicting goals. Botanists who are trying to achieve riparian vegetation recruitment and succession would seem to be uniquely qualified (in their understanding of these processes) to help biologists who are trying to forestall vegetation recruitment.

Introduction. This document characterizes the vegetation observed on riverine sandbars across the southern portion of the ILT breeding range, with an emphasis on the species and natural succession processes that are important to the maintenance of SNH. The characteristics of SNH are more specifically defined in Lott and Wiley (2012), to which this document is closely related. The recommendations herein are applicable to the management of vegetation on each of the major southern rivers with large ILT populations: the Lower Mississippi, Red, Arkansas, Canadian, and Cimarron (Lott 2006).

While some of the species and vegetation communities that are explicitly discussed in this report (especially bagpod [(*Sesbania vesicaria*)]) are more common within the southern portion of the ILT breeding range, many of the same species and vegetation management challenges occur on the Missouri and Platte Rivers of the northern Great Plains, which contain breeding populations of both ILT and GPPP (USDOI 2006, USACE 2011).

Given the topographic diversity of riverine landforms and the high frequency of accessible soil water, riparian vegetation species diversity is expectedly high on Southern Plains Rivers (Woods et al. 2005; Hoagland 2008). More than 300 plant species were identified during field surveys on the Red, Arkansas, and Canadian Rivers in 2008-2009 and a comprehensive multi-season survey of this region might yield a species list numbering in the low thousands.

While vegetation diversity is interesting to the botanist, only a few dominant plant species comprise a small number of vegetation habitat types within the high bank confines of the riverine corridor. Understanding the biology of the dominant species that quickly colonize and persist on bare sandbars is critical to understanding how vegetation may be managed to maintain SNH. Knowledge of ***why*** particular plants repetitively occur on riverine sandbars is central to the effective management of SNH, especially the key processes of vegetation recruitment and mortality.

Species of plants form repetitive groupings, or communities, the composition and distribution of which are strongly segregated along elevation-mediated hydrologic and flooding gradients (Johnson et al. 1976, Hupp 1990, Hoagland 2008). By considering only vegetation management for sandbar nesting bird populations, riparian vegetation on sandbars was classified into 10 “habitat types,” based on ecological/structural characteristics that were discernible from both field surveys and aerial imagery. These groupings may vary slightly in species composition, due to changes in climate and elevation along rivers; however, structural habitat types remain broadly similar due to the persistence of several dominant forms given the ecological processes that underlie their occurrence. The most effective management options for different “habitat types” will often remain the same as species composition varies.

While many plant species were identified during field surveys, only 20 “dominant species” were identified in this study, which comprised ≥20% ground cover density in vegetation stands at one or more sites. Of these, seven “keystone species” were singled out as occupying greater than 50%

ground cover in many stands. Understanding the ecological and reproductive characteristics of these 20 dominant species allows for development of management plans directed toward reducing the rate of vegetation establishment in SNH.

While the successional processes of each of these 20 species may be important at some location or in some set of environmental conditions, this report focuses in particular on the autoecology and successional patterns of the three most abundant keystone species (cottonwood [*Populus spp.*], willow [*Salix* spp.], and bagpod) on Southern Plains rivers, due to their very high fecundity and their ability to quickly colonize freshly exposed sand. The establishment of any one of these species effectively limits the number of years that a sandbar may be suitable for nesting.

How sandbar vegetation may limit ILT nesting habitat use or reproductive success. Sandbar vegetation may limit nesting bird populations in two ways. First, if sandbars are fully vegetated, birds will not select them for nesting (Thompson et al. 1997). At multi-year scales, if perennial woody species become well-established and high flows can no longer remove vegetation from sandbars, sandbars succeed to forest, river channels narrow, and SNH loss may be permanent (Williams and Wolman 1984, Stinnett et al. 1988, Friedman et al. 1998, Johnson 2000).

Second, vegetated sandbars may be more heavily used by predators than bare sandbars, which may limit tern reproductive success (Kruse et al. 2001). The widespread presence of vegetation on nesting sandbars, even at low stem densities, can increase the likelihood of nest or chick depredation by predators, since colonization of sandbar sites by vegetation is quickly followed by animal colonization. Small invertebrate herbivore colonization is followed by insectivores, herbivorous vertebrates, and then small predators, until a prey base is established. Once there is sufficient prey for a larger predator to hunt the site on a regular basis, tern and plover nests and chicks become seasonal additions to their diets. Suppression of vegetation is then a concern for maintaining a sandbar's suitability for nesting and for minimizing predator-induced mortality.

How vegetation management may supplement other habitat conservation strategies. The objective of this section is to advance both general and context-specific principles for the management of sandbar vegetation when the manager's goal is to maintain barren sandbars as high-quality nesting habitat for ILT or GPPP. The authors are currently unaware of any active vegetation management programs like the one outlined in this technical note. This is problematic, since the placement of large dams on rivers has reduced the frequency and magnitude of flooding events that create new bare sandbars to the extent that the abundance or quality of nesting habitat may be low enough to limit ILT population growth (USFWS 1990, 2003, 2005a, 2006).

On some highly regulated rivers, direct management of SNH may be necessary to sustain regional ILT populations. This management could include: 1) changes to flow regimes to increase the frequency of floods that would result in new sandbar habitat creation; 2) relatively costly programs to mechanically create restoration sandbars; or 3) active management of sandbar vegetation so that existing sandbars with suitable nesting habitat are not lost so quickly to pioneering vegetation establishment and succession. Of course, any combination of these three strategies could be employed in any area, depending on the inherent flexibility (or lack thereof) in rule curves (water control practices at dams that govern upstream and downstream water levels), the availability of funds for sandbar restoration or vegetation management, and feedback from stake-holders. Habitat-

forming floods are relatively infrequent and mechanical sandbar creation is tremendously expensive. Therefore, the authors suggest that integrated vegetation management (involving flow manipulations, hand or mechanical vegetation removal, and potentially, chemical applications) could be employed more regularly than it is now to sustain the duration of infrequent and periodic gains in SNH that result from flooding or mechanical habitat creation.

Triggers for vegetation management to maintain SNH. Various authors have observed that Least Terns will nest in vegetation densities of up to 30% (summarized in Thompson et al. (1997)). Least Tern nesting has been observed on completely bare portions of sandbars on the Missouri, Platte, Mississippi, Arkansas, Canadian, and Red Rivers. These observations include time periods when sandbars were completely free of vegetation (e.g., after the formation of a new sandbar during a high-flow event), as well as later in the post-depositional sequence of plant succession, when birds chose bare portions of sandbars to nest as opposed to areas with dense or even sparse vegetation. The authors suggest that extensive areas of completely barren sand, particularly those at higher elevations relative to flows during the Least Tern breeding season, are preferred for nesting (Lott and Wiley 2012).

It should be stressed that once any "threshold" value for vegetation density is reached, vegetation succession is often well underway, and nesting habitat may be on a one-way path towards unsuitability. Therefore, the presence of *any* vegetation at high elevations on sandbars should be considered a threat to SNH, and a call for management action, regardless of vegetation occupation density estimates, particularly if the occupying plant species is one of several that spreads rapidly or becomes progressively more difficult or expensive to manage over time.

Consequently, vegetation management (e.g., vegetation removal at the higher elevations of nesting sandbars) will be most effective if implemented as early as possible (e.g., as soon as germination is detected), regardless of stem density. Waiting to reach an inevitable stem-density threshold will make vegetation removal more difficult, costly, or impossible. USDOI (2006) and USACE (2011) chronicle the difficulty of vegetation removal once primary succession has already occurred.

This document emphasizes the importance of understanding plant species biology and processes of vegetation succession in ways that monitoring and management efforts can be focused on rapidly detecting and addressing vegetation encroachment that may lead to nesting habitat loss (e.g., plant recruitment at nesting elevations during the first growing season that recruitment occurs). The earlier that new vegetation is detected within the successional sequence, the more options will be available for vegetation removal, with higher probabilities for success (e.g., forestalling the loss of nesting habitat), at the lowest costs.

Habitat types. Habitat types occur in repetitive associations distributed along environmental gradients. Plants respond to all effective environmental influences simultaneously; however, the most compelling influence within a major riparian area is the characteristics of the hydrologic regime, both during and outside of the growing season (Mahoney and Rood 1998). During the growing season, the frequency of inundation or saturation within the root zone and the duration of oxygen-free soil conditions, or conversely, the rapidity of desiccation and the persistence of drought, are powerful non-random segregators of plant species distribution.

Throughout the year and over periods of years, changes in water level associated with flooding (particularly infrequent higher energy events) select for and segregate among species for those tolerant to or benefited by the effects of flooding, particularly in terms of the capture, transport, and distribution of propagules. These propagules typically are seeds, but can also include large and small willow and cottonwood stems that will resprout on newly created surfaces. Flooding also deposits, removes, winnows, and segregates soil materials by particle size and specific gravity. Soil particle size distributions affect water retention, nutrient availability, and resistance to water and wind erosion, reinforcing repetitive patterns.

Both the presence of water near the surface and the frequency and magnitude of effects of flooding operate along a topographic gradient. Lower relative elevations in a channel are subject to more frequent and more persistent inundation or saturation within the rooting zone. Lower relative elevations are also subject to more frequent, lower-energy flood events and are most susceptible to drastic substrate modification during high-energy flood events. These elevation-mediated conditions result in distinctive vegetation zones that support repetitive species groupings (Turner et al. 2004).

Some of the species that comprise the habitat types identified here change along climatic and latitudinal gradients within river corridors. Often the replacement is by a species within the same genus or plant family. Sometimes replacement is by another group altogether. However, structure and form of the new group are often similar due to the similarity of physiology necessary to tolerate the consistent effects of flooding, root anoxia, or drought.

Local, relative elevation above a fluctuating river stage serves as the primary plant association segregating factor. Plant associations assemble and form over growing seasons and over years between flood events. Those associations initially dominated by annual herbaceous plants demonstrate a much shorter period of stability than a forested riparian area. As a result, the presence of particular vegetation associations expresses the frequency and importance of water stage across growing seasons and years, without regard to the stage during an instant observation. Table 1 summarizes the 10 habitat types defined for riparian areas with nesting ILT or GPPP. Habitat types are sorted from lowest to highest relative elevations, with comments on the ecological conditions that drive their presence.

Keystone and dominant species. Plants possessing the characteristics most suited to the extremes of the riverine environment (that is, high tolerance to frequent structural damage from wind and flooding, tolerance to episodic anoxia and drought, rapid germination and growth, high fecundity, and long life), have the greatest likelihood of persisting in the riverine environment. Species with these characteristics are the “keystone” species of the riverine corridor. Keystone pioneering species occupy newly barren ground quickly and often prepare the site for occupation by other species. The three keystone species most important to the management of natural succession on large rivers of the Southern Great Plains are eastern cottonwood, black willow, and bagpod. These are the first to arrive and facilitate the establishment of other species. Four other species (yellow-nut sedge, cocklebur, winged pigweed, and switch grass) qualify as keystone species by virtue of ground cover density at some sites. Table 2 lists the seven keystone species on large rivers of the Southern Great Plains and classifies them by the threat they pose to SNH and their timing in the arrival sequence on newly formed bare sand.

Table 1. Vegetation habitat types on the Red, Canadian, and Arkansas Rivers in Oklahoma.

Vegetation habitat type	Description (dominant species listed below)
Submerged Aquatic Vegetation	Perennially inundated; lowest vegetated habitat; low-energy shorelines, back channel sloughs.
Species: American Waterweed, Curly Pondweed, Arrow-Head, American Water-Plantain, Cattail, Soft-stem Bulrush, Common Pondweed	
Spike-rush Mudflat	Found on low pool fringes, lower banks, filled-in backwater chutes, filled-ponds and depressions underlain by fine materials on sandbars. Persistent, but may be replaced by cattail marsh.
Species: Least Spikerush, Stink-Grass, Ditch Stonecrop, Slender Flat-sedge, Common Spikerush	
Hydrophytic Sedge-Grass-Herb (LOWVEG)	Perennial colonial association forming at the water edge of sandbars and shorelines. Mixed annual and perennial graminoid and herbaceous species with water-borne seeds. Yellow Nut-sedge strongly dominant to monotypic. Elevated 1.5 ft above to 0.1 ft below modal growing season water elevation. "LOWVEG" line is used as an index for the position of the most frequently occurring water line during the growing season, visible even in low water conditions.
Species: Yellow Nut-sedge, Red Ammannia, White Smartweed, Marsh Fleabane, Swamp Milkweed, Least Spike-rush, Wild Radish, Soft Rush, French Tamarisk	
Annual Herb	Sparsely to densely vegetated lower mesic sandbar terraces and shorelines. Usually found 1-4 ft above LOWVEG line. Few species, often Bagpod monocultures and mixtures of wind-collected weeds.
Species: Bermuda Grass, Bagpod, Cockle-bur, White Vervain, Switch Grass, Goose Grass, Elongate Bladder Pod, Winged Pigweed	
Mixed Herb	Perennial herbs and grasses in mesic to xeric conditions on sandbar and recently disturbed banks and shallow slopes. Long persistent but will transition to woody species with time. Occurs 2 to 10 ft above LOWVEG line.
Species: Bagpod, Sandspur, Partridge Pea, Cockle-bur, Hogwort, Indian-hemp, Common Crabgrass, Winged Pigweed, Mist Flower, Gumweed	
Mixed Herb-Shrub	Supplants mixed herbs and precedes various upland floodplain forest types. Stands 4 to 10 ft in height.
Species: Cottonwood, Red Cedar, French Tamarisk, Switch Grass, Sycamore, Amaranth, Hogwort, Winged Pigweed	
Perennial Grass	Switch Grass-dominated, but includes mixed grasses and upland herbs on terraces 4 to 20 ft above LOWVEG line.
Species: Switch Grass, Johnson Grass, Sandspur, Redtop, Goosegrass, Bermuda Grass, Common Crabgrass, Winged Pigweed, Hogwort, Cottonwood, Partridge Pea	
Willow Thicket	Saplings in frequently-flooded to mesic conditions on slopes, low flood benches, side channel benches, depressions, and upper deltas from side channels. Perennial, woody, and persistent with Black Willow strongly dominant. 4-20 ft ht.
Species: Black Willow, Chinese Elm, American Elm, Green Ash, Slippery Elm, French Tamarisk, Button-bush, American Sycamore	
Gallery Forest	Highest elevations in riparian corridor. Level to moderately sloping, rarely flooded. Perennial woody and semi-persistent trees.
Species: Eastern or Plains Cottonwood, Eastern Red Cedar, Green Ash, American Sycamore, Common Juniper	
Successional forest	Climatic climax forest. Longest period since disturbance. Perennial, woody and persistent. Top of Bank and beyond.
Species: Southern Hackberry, Basswood, Burr Oak, Red Cedar, Post Oak, Pecan, Green Ash	

Table 2. Keystone species for natural succession on riverine sandbars in the study area.

Species	Arrival sequence	Threat to nesting habitat
Black Willow (*Salix nigra*)	2	Very High
Yellow Nut-sedge (*Cyperus esculentus*)	1	No
Eastern Cottonwood (*Populus deltoides*)	2	Very High
Bagpod (*Sesbania vesicaria*)	1	Very High
Cocklebur (*Xanthium strumarium*)	2	High
Winged Pigweed (*Cycloloma artriplicifolia)*	3	High
Switch Grass (*Panicum virgatum*)	3	Moderate

Both yellow nut-sedge and bagpod generally arrive *during* sandbar formation due to the ubiquity of their buoyant and durable seeds. Yellow nut-sedge occupies only the lower fringes of sandbars within rooting depth of a shallow water table associated with normal stage during the growing season (Figure 1). Because this is a frequently flooded zone, and terns and plovers prefer to nest in dry areas, yellow-nut sedge never threatens loss of nesting habitat. In fact, the presence of yellow nut-sedge should be considered desirable due to the erosion resistance it contributes to sandbar margins.

Figure 1. Well downstream of several hydropower dams in Oklahoma, Yellow-nut sedge becomes the dominant vegetation along the modal growing-season waterline, which is associated with recurring peak-hydropower releases from upstream dams. It is particularly dominant in this position due to its tolerance of several days of desiccation when dam releases are curtailed during periods of low power demand (e.g., weekends). This waterline vegetation community stabilizes the shoreline of large sandbars, reducing lateral erosion, and prolonging the life of Least Tern SNH.

In contrast, bagpod presents a serious management problem, since it occupies higher elevations that are likely to be used for successful ILT nesting during normal flow conditions and serves as an important nurse crop for seeds of wind-borne species, both during its reproductive life and the following growing season, due to its persistent semi-woody stem (Figure 2).

Figure 2. Bagpod encroaching on a newly formed sandbar. Line of willow, successional forest, and gallery forest in the background.

Since their seed viability period is brief (less than 3 weeks), both black willow and cottonwood arrive by wind and water during the first growing season after a sandbar has been formed. Most initial establishment is from water-borne seeds distributed along sandbar shorelines. However, if bagpod is already established, both species will also be collected from the wind stream. Cottonwood seedlings will survive along the upper elevations of the bagpod occupation area, while black willow will segregate to the lower, moister elevations. Growth of both species may render nesting habitat unsuitable within 2- 5 years (Figure 3).

Once any of these species can support perching birds, fruiting species such as wild plum, wild black cherry, choke cherry, and eastern red cedar will become established through avian-dispersed seed. As soon as shrubs/trees reach a height where they serve as perches for avian predators, their negative influence on ILT/GPPP use of sandbars may extend to many hundreds of feet around them (USACE 2011, Appendix B). Three additional keystone species (present at >50% ground cover on more than one site in the study area) are cockle-bur, winged pigweed, and switch grass (Figure 4). These species are delivered to sandbars by wind and animals, and often arrive at sandbars once bagpod, cottonwood, and black willow have prepared the site for seed collection and mitigated the prevalent xeric conditions. Both cockle-bur and winged pigweed fruiting structures bear recurved spines that greatly facilitate their retention in existing vegetation and on coarse surfaces of aeolian pavements that form on most sandbars. Control of cockle-bur, winged pigweed, and switch grass (as well as many other plant species that can become dominant on sandbars) is perhaps best achieved via initial aggressive control of bagpod, willow, and cottonwood.

Figure 3. The two pioneering riparian species that are most responsible for sandbar nesting habitat loss are willow (foreground) and cottonwood (background). The dominant species of willow or cottonwood causing SNH loss varies across the range of ILT and GPPP; however, both synecological and autecological relationships are assumed to be functionally similar.

Figure 4. Sandbar dominated by switch-grass (left). Cocklebur encroaching on nesting habitat (center). Winged pigweed detail (right). Each of these three species can become dominant at some sites, resulting in SNH loss.

Vegetation succession on sandbars. After erosion has molded newly deposited sands to relatively stable forms, vegetation encroachment is the most important factor accounting for the loss of SNH. However, shoreline stabilization against further erosion of elevated SNH sites, such as the development of yellow-nut sedge monocultures on the perimeters of nesting sandbars, is a positive effect of vegetation establishment. Sandbars that persist longest as SNH tend to have features that resist vegetation encroachment in elevated portions, while supporting shoreline fringe vegetation. The juxtaposition of these negative and positive values of vegetation may argue against the use of broadcast herbicides to maintain SNH for ILT in some contexts.

Whether sandbars are created by fluvial processes or mechanical means, all new sandbars present opportunities for colonization by pioneering vegetation. Vegetation colonization proceeds inexorably from the moment that a new sandbar is created, until it is fully vegetated and unusable

by sandbar nesters. Knowledge of processes of vegetation colonization on freshly created sandbars helps to maximize the persistence of sandbars as SNH. Seeds and vegetative propagules of riverine plants are deposited with sand during sandbar formation. Most are buried or deposited in unsuitable growth locations, and will never produce viable plants. However, the number of such propagules is so large that survival of even a fraction of a percent is sufficient to colonize most newly deposited sandbars. In addition to this inherent propagule load, new propagules are constantly delivered to the waiting site by wind, water, and animal vectors. These propagules either immediately find conditions suitable for germination and growth or they do so at some time later when conditions become suitable.

Primary succession on sandbars is dominated by two woody species in the willow family (*Salicaceae*) that rapidly colonize sandbars: cottonwood[1] and black willow. These are often the pioneer species on a sandbar due to their similarity of seed propagation and their staggering fecundity (Bessey 1904, Karrenberg et al. 2002). Seeds are lightweight and tufted, and thus both wind- and water-borne for both short and relatively long distances. Seeds are produced in great quantities and their initial viability approaches 100% (Engstrom 1948, Bessey 1904). Both species also reproduce vegetatively (clonally) through viable stem and root fragments (Fowells 1965, Bradley and Smith 1986, Douhovnikoff et al. 2005). Willows are more effective at this latter reproductive strategy, since their viable fragments distributed by water are suited to relatively long periods of anaerobic respiration (Dionigi et al. 1985). Both of these woody species serve as wind and water flow energy reducers. Acting like snow fencing, their simple physical effect is to interrupt laminar air flow, trap seeds and other propagules, and prevent them from being easily remobilized. This allows for the possibility of a stable germination or new root development period for many other plant species.

Cottonwood and willow stands also trap both airborne and water-borne sediments and organic detritus. The majority of these are the finer fractions (fine sand, silt, and clay-size particles) and light fragments of organic matter. These materials improve water retention as they collect on sandy substrates and improve nutrient availability for growing propagules. The stems and canopies of cottonwood and willow offer physical protection to growing sprouts. Potentially damaging wind and water flow effects are buffered. Temperature changes and extremes are moderated. Leaf drop by deciduous woody species provides additional organic mass to the substrate, increasing nutrient availability and water retention.

All of these processes proceed geometrically in effectiveness over time (Decamps and Tabacchi 1994, Dykaar and Wigington 2000, Karrenberg et al. 2002, Fierke and Kauffmann 2006). Lacking the establishment of these two woody species, other plants will eventually find a wet season or a crevice to establish themselves; however, the time is usually greatly extended. For example, high dam releases on the Missouri River in 1997 formed many high-elevation nesting sandbars that remained barren for 6-8 years after the flood due to their inhospitality for seed germination and growth (USACE 2011). The primary physical/biological factor that allowed for sandbar persistence as nesting habitat in this context was the deposition of large amounts of sand at high elevations relative to growing season water levels. Post-depositional wind erosion quickly removed

[1] Cottonwood includes eastern (*Populus deltoides* Bartr. var. *deltoides*) and plains (*P. deltoides* var. *occidentalis* Rydb). Var. *deltoides* ranges west in the study area Var *occidentalis* is mapped within western river segments in the study area, with the closest populations mapped upstream of Texhoma Lake (Fowells 1965).

fine particles from these high sandbars, creating a matrix of coarse substrates that allowed for rapid drainage at high elevations. This characteristic has been observed on newly formed sandbars on many rivers across the range of ILT and GPPP (Figure 5).

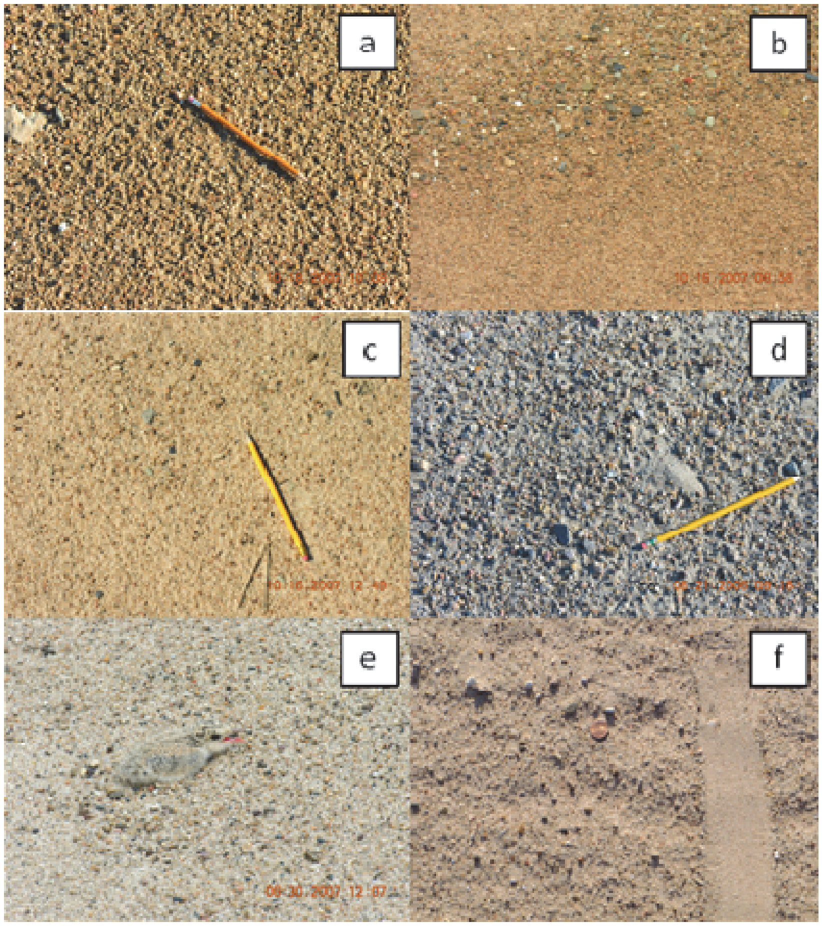

Figure 5. Bare sand substrates dominated by medium to coarse sands (but ranging from medium sand to fine gravel) are the preferred nesting substrate for interior least terns. Once new, high-elevation sandbars are exposed after high-flow events, sand particles lose their adhesion as they dry and finer particles on sandbar surfaces are removed by wind action. Despite the dominance of fine particles in suspended sediment, aeolian erosion after high sandbar formation tends to produce the types of coarse substrate sandbar surfaces shown here on each of the major sand bed rivers within the range of ILT: a) Arkansas River below Kaw Dam; b) Arkansas River below Keystone Dam; c) Canadian River below Eufaula Dam; d) Missouri River below Gavins Pt. Dam; e) Mississippi River in Missouri; f) Red River below Denison Dam.

Coarse sands that are present at high elevations relative to water elevations during willow and cottonwood seed dispersal prevent the moist soil conditions that lead to germination. Rapid drainage of these substrates also causes mortality of many young seedlings that are able to

germinate due to desiccation. On rivers where the elevation difference between the highest sandbar elevations and the river surface is greatest during the growing season, cottonwood and willow management may only be a periodic necessity, following events where high flows during seed dispersal deliver seeds and promote germination at nesting elevations. Alternatively, for rivers with small elevation differences between the tops of sandbars and the growing season water surface, willow and cottonwood management may be a chronic (and perhaps losing) battle (Figure 6). This observation argues for the restoration of sandbars higher in relative elevation (within practicable upper limits) when long-term active SNH management is part of a riverine habitat management plan.

Figure 6. Due to the small elevation/stage difference between common growing season water levels and the highest elevations of sandbars, Platte River sandbars are rapidly colonized by willow and cottonwood. Saturated soils, connected to the water table, provide outstanding conditions for seed germination. In the absence of periodic high flows that remove existing sand-bars with vegetation and create new bare sandbars, channel narrowing may occur.

Management of sandbar vegetation

General principles for effective vegetation management. Bare sandbars form in natural depositional areas within channels, the number of which may be regionally limited due to channel geometry and fluvial processes. Allowing these areas to become forested may result in the long-term loss of areas where bare sandbar formation could be possible during subsequent high-flow events (Friedman et al. 1998). This type of long-term habitat loss should be avoided as much as possible (Johnson 2000).

The most important principle of vegetation management is the following: *the earlier that vegetation management occurs, the more effective (and less costly) it will be*. Therefore, the most cost-effective way to manage vegetation is to have no vegetation to manage. For this reason, the authors suggest a tiered management approach that focuses on: 1) managing flows to limit seedling germination or cause young seedling mortality; 2) relatively simple and cost-effective methods for physically removing first-year recruits before the end of their first growing season (after the tern and plover nesting season); and 3) more costly methods for vegetation removal (that also require new sand deposition) to restore sandbar deposition zones once succession has advanced far enough for the simple physical removal methods in step 2 to become infeasible.

Since costs increase and effectiveness decreases at each of these steps, river managers are encouraged to more strongly consider developing active management strategies centered around the recommendations for steps 1 and 2 above, which require relatively simple monitoring followed by rapid management response early in the sequence of vegetation succession, rather than waiting until habitat becomes unsuitable and more costly actions are required. Ultimately, in the absence of major changes in large-flood regimes that seem unlikely on most regulated rivers where ILT and GPPP occur, vegetation management strategies that allow for more bird reproduction on newly created sandbars, whether these are created by high dam-releases or mechanically, may be the most efficient and cost-effective way to maintain adequate amounts of SNH on highly altered regulated rivers. Figure 7 provides a conceptual model of vegetation management options at various steps within the sequence of natural succession/sandbar nesting habitat loss. The earlier that action is taken in this sequence, the higher likelihood of success in maintaining SNH and the lower the costs.

Managing sandbar vegetation with dam releases. When developing a vegetation management strategy, river managers and botanists should work together to explore options for the development of rule curves (or slight modifications to water control practices) that discourage seedling recruitment at nesting elevations on sandbars. *This step focuses on ways to avoid or minimize the extent of a problem (vegetation establishment on sandbars) that is both difficult and costly to address.* This type of management will require greater collaboration between water managers and biologists than typically occurs across much of the ranges of ILT and GPPP. However, the authors believe that this type of collaboration is essential to ensure the long-term persistence of SNH. Once vegetation is established on sandbars, vegetation removal becomes increasingly costly and less effective with time (USDOI 2006, USACE 2011). Consequently, the most effective vegetation management practice (and one that is rarely explored) would be to alter reservoir operations so that: 1) long-duration high and stable flows during peak seed dispersal do not promote seed germination at high elevations on nesting sandbars; 2) young seedling mortality can be induced via inundation or desiccation during targeted (and often minor) short-term flow reversals (either increased or decreased) when young plants are most vulnerable, immediately after germination; and 3) flows are manipulated to promote the mortality and complete removal of young seedlings from sandbars due to flooding (which results in both erosion and new sand deposition), desiccation, or ice-scour at any point before the beginning of their second growing season.

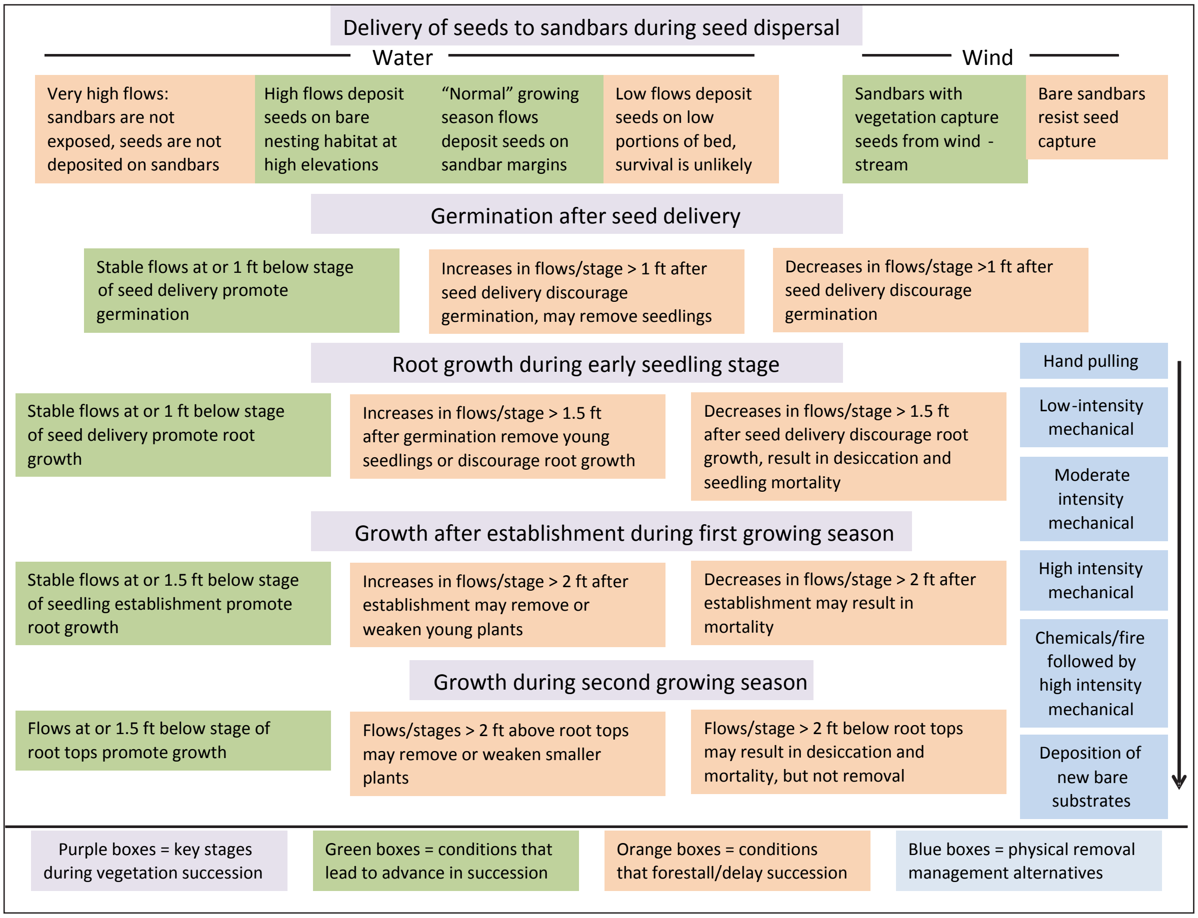

Figure 7. The five key stages of vegetation succession on nesting sandbars (purple boxes). Green boxes indicate conditions that tend to advance succession to the next stage. Orange boxes indicate conditions that tend to forestall or delay succession. Some conditions are uncontrollable, but others can be influenced by well-timed, targeted flow management. Blue boxes indicate management treatments that involve physical vegetation removal, sorted top to bottom by increasing cost/intensity. The earlier that succession is detected and acted upon, the more efficient (and cost-effective) management to maintain bare SNH will be. This will require clear communication between on-the-ground monitoring crews, managers that negotiate budgets and permissions for vegetation removal, and on-the-ground vegetation removal crews.

Johnson (2000) provided guidelines for how this type of flow management could work on the Platte River. Unfortunately, Johnson's recommendations have not been successfully implemented on the Platte, partially due to the advanced state of channel narrowing on this river (which is very difficult to forestall given the relatively small stage difference between growing season flows and the highest elevations on most sandbars), and partially due to constraints of system operations related to the over-allocation of water. However, flow management to avoid plant recruitment and encourage young-seedling mortality on nesting sandbars may be more feasible and effective on other systems, with better initial habitat conditions, different channel configurations, and/or greater operational flexibility.

Options 2 and 3 (above) may seem similar, but they are listed separately here, since the longer new recruits have to establish their root structures, the more likely they are to survive subsequent floods

or dry periods of increasing magnitudes. Consequently, very minor flow reversals may be effective to induce mortality immediately after germination, whereas larger flow reversals may be required to induce mortality later in the growing season or in winter.

Moderately high mid-summer dam releases (whether for flood control or navigation) have the effect of enhancing vegetative succession on the high elevation portions of sandbars. These areas represent the highest quality SNH, since they tend to resist plant establishment (due to their height above water during normal growing season dam operations) and present less risk than lower elevations to nest or chick mortality due to flooding. This problem is exacerbated when flood control releases are held at constant water levels for many consecutive days, which occurs as a function of many dam-specific rule curves for flood control (USACE 2002, 2003, 2004). When flood-control releases occur during peak cottonwood or willow seed dispersal, ubiquitous water-borne seeds or propagules may be delivered to high-elevation portions of sandbars, where they will be likely to encounter the sustained saturated soil conditions necessary for germination. In systems where bagpod seeds are a persistent component of wrack materials, high flows during any season may deliver viable bagpod seeds (which can remain dormant for long periods) to high elevation portions of sandbars (see section below titled “Management of Bagpod”).

Rather than losing high-quality, high-elevation sandbars to cottonwood, willow, or bagpod recruitment, short-term increases or decreases in dam releases (within the period of weeks required to draw reservoirs down to desired pool elevations during flood-control operations), could cause the mortality of young seedlings due to flooding or desiccation (see Johnson (2000) for details and Figure 7 for a conceptual diagram). Since either type of flow reversal should result in the mortality of young seedlings, the direction of flow reversal (e.g., increase or decrease) could be decided upon based on short-term needs for system storage once recruitment at nesting elevations was reported by field monitoring crews. *This provides a flexible framework for management, where flow management alternatives can be assessed on a case-by-case basis, only after recruitment is detected, relative to current system storage and demands for water.*

Determining the reach-specific magnitudes and durations of flow increases or decreases that cause seedling mortality may require some experimentation. However, this management approach may be the most effective way to address the most common cause of loss to high-quality SNH (e.g., recruitment of cottonwoods or willows at nesting elevations), since removal of either species after establishment is difficult, time-consuming, and costly. This type of management may require revision to water control manuals or dam-specific operating plans (e.g., USACE 2002) to give water control the necessary flexibility to initiate flow reversals.

Similar to the problem of stable high flows, the presence of stable and relatively low flows late in the growing season (whether for irrigation water supply, water quality, or hydropower production) may enhance the growth and expansion of the willow-dominated zone by maintaining root saturation at a time of year when, on unregulated rivers, hydrographs would tend to fall rapidly, resulting in root desiccation and mortality of many young seedlings. Flow reversals to induce young-seedling mortality may need to be larger (or longer in duration) late in the growing season than flows that were effective shortly after germination, as plants will develop stronger root structures as the growing season progresses. Late in the growing season, low flows that are designed to induce mortality through desiccation may be more regularly

feasible than high flows (to induce mortality through inundation or the dislodgement of young seedlings) since low flows are more common during this time of year to maintain late summer reservoir storage targets for water supply during periods when reservoir inflow is low.

The viability of either type of mortality-inducing flow will likely vary among systems and among years. Whenever new vegetation recruitment has been detected, water managers should begin to consider the use of short-term targeted flows to induce young seedling mortality as soon as possible (followed by complete removal of dead stems so that they do not serve as seed-traps or mulch in the future). If this is not feasible at any point after recruitment during the growing season, physical removal of first-year recruits will be the next preferred course of action (Figure 8). However, given the difficulty and costs associated with physical removal, river managers should very strongly consider flow removal alternatives whenever recruitment events are detected in high-quality, high-elevation SNH.

Figure 8. While aggravating and time-consuming, these first year cottonwood seedlings can easily be removed by hand without destroying the underlying coarse sand substrate that could serve as future Least Tern nesting habitat. If this recruitment event had been detected earlier by monitoring crews, hand removal would have been even easier. If recruitment events such as this are undetected, or if managers are too slow to respond, vegetation removal will become much more difficult and costly by the next growing season.

Physical removal of first year cottonwood and willow recruits. Since vegetation removal becomes so difficult and costly after two growing seasons, the next highest priority, after managing flows to dissuade recruitment (which may not always be possible) should be removing first-year seedlings before the end of their first growing season. This can be done by hand-pulling young cottonwood and willow seedlings as soon as possible after the tern nesting season. At this point, first year cottonwood and willow recruits provide little resistance to hand pulling and are easily removed. During this same time period, all desiccated stems that may provide mulch for subsequent seed capture should be removed as well (via hand pulling or raking, without removing driftwood debris at high sandbar elevations, since terns often place their nests uphill of this debris,

and it may serve as a cue to reduced flooding risk). Hand pulling (perhaps supplemented with limited raking) is strongly preferred to other means of young stem removal, since it results in the complete removal of all vegetative biomass from the high elevations of sandbars. This eliminates the possibility that this biomass will trap seeds in subsequent growing seasons and presents terns with the barren coarse sand substrates that typify the high-elevation portions of sandbars frequently selected for nesting.

Figure 9. Vegetation removal must result in the complete removal of all organic debris, not only the death of target plant species. Chemical applications followed by mowing, as illustrated here, will not result in persistent habitat renewal, since both the live vegetation in untreated areas and the remaining organic debris in treated areas will very likely result in vegetation encroachment by assisting next season's recruitment. A few birds may nest in the treated area in year one, but not many, due to its small size and proximity to live vegetation. By year 2, very little bare sand that is appropriate for nesting will be available. The cost-benefit ratio of such efforts is likely to be low.

If young seedling recruitment is too extensive or stems are too large for effective hand removal, mechanical means such as mowing, brush-hogging, or low-intensity controlled burns could be effective in inducing young cottonwood mortality; however, these practices will be less effective for willow, since they could promote vegetative reproduction through root sprouting.

Regardless of plant species, complete removal of all mowed stems is necessary after mowing to keep sandbars completely barren, since remaining stems and debris will promote seed capture and facilitate seedling survival in subsequent years. Disposal of chopped and cut vegetation might be achieved by using a mulcher to blow material directly into the flowing river. Environmental effects of such disposal may be negligible compared to the annual load of allocthonous material provided to rivers by deciduous trees. If complete removal of vegetation has the undesirable effect of

reducing sandbar elevations (and increasing nest flooding risk), sandbars where vegetation has been removed may need to be capped with new sand to replace lost elevation.

Physical removal of vegetation after primary succession has occurred. Once vegetation density or stem size increases such that mowing or burning is not possible, and heavy equipment needs to be delivered to the site, a sandbar is very likely to be less than one breeding season away from becoming unsuitable nesting habitat. At this point, the priority becomes not allowing succession to advance so far that mechanical removal of all vegetation is impossible (using whatever heavy equipment suits the task). When heavy equipment is required for removal, two additional steps will be required to keep the site free from vegetation in the future.

First, the removal process should include the additional step of clearing all brush piles/stems from the site (particularly for species where cut stems and remaining root systems act as propagules) (Figure 10). Second, a dredge should be used to completely cap the site with new sand, to regain any sandbar elevation that may have been lost during vegetation removal and so that any propagules remaining in the seed bank are buried too deeply to re-sprout. The material that is used to cap sandbars from which vegetation has been removed should come from deeper parts of the channel/lower elevations on sandbars so that newly deposited sediment is not laden with dormant and viable seeds. Capping a sandbar with sand that may contain heavy propagule loads defeats the purpose of this step. The costly process of "turning a sandbar upside down," which is described here, should be reserved for areas where successful completion of this task has the potential to support tern nesting for many years.

Figure 10. Two- to four-year-old stand of black-willow, smartweed, burdock, and switch-grass. Hand removal is no longer possible. Incomplete removal of well-developed roots may result in re-sprouting. Options at this point are limited to extensive operations with heavy machinery. Since this will likely result in a major loss of sandbar elevation, this would need to be followed with deposition of additional sand (not containing seeds of pioneering species) to replace potential nesting elevations. At this point, vegetation removal is both very costly and marginally effective.

Specific strategies for cottonwood, willow, and bagpod. Focal management of cottonwood, black willow, and bagpod will often be necessary due to the critical ecological function of these three species as "nurse" stands for the invasion of other vegetation on elevated sandbars suitable for nesting. Cottonwood is a rapid colonizer of newly barren and well-drained substrate (as long as substrates are moist during seed dispersal). Black willow becomes established in wetter, more frequently flooded areas that are less suitable for nesting, but has the potential to move to higher elevations on sandbars due to vegetative reproduction after initial colonization. Bagpod is often the first species to occupy newly formed sandbars and may prepare the site for occupation by other species. An effective vegetation management program will almost certainly need to focus on aggressive control of these three species. The biology of willow and cottonwood on many of the rivers where ILT occur has been extensively studied (reviewed in Johnson 2000 and USACE 2011, Appendix B) and readers are referred to these excellent sources. In contrast, bagpod is far more common in southern portions of the distribution of ILT than at northern latitudes, and has received considerably less research attention. Consequently, some additional detailed information on the biology of bagpod is provided in this note.

Management of bagpod. Bagpod is a very highly successful plant, well adapted to proliferation on riverine sandbars. Few natural biologic controls are known to be effective against bagpod at the field scale. It seems to be limited in area of occupation on new sandbars by the local elevation of surfaces above frequently occurring river water levels. Dense stands were rarely observed during the 2008 field survey to be more than 4 ft higher than the Yellow nutsedge community typical of sandbar-river fringes.

The USFWS southwest refuges management plan (*http:// www.fws.gov/southwest/refuges/Plan/docs/Chapter%203.pdf*) (USFWS 2009) recommends roller chopping, rapid summer drawdown of river stages to limit germination, and frequent mowing and disking during the growing season. USFWS (2009) also recommends the use of herbicides labeled for aquatic use. Marshall (1989) suggested that defoliates may be effective in aborting fruit formation, but only if bearing branches are fully defoliated. The structure of mature plants tends to protect lower branches from aerial deliveries of herbicides; however, Marshall (1989) demonstrated that mechanical abrasion and leaf removal significantly improves herbicide effectiveness. Herbicide applications may be most effective on emerging seedlings. Pre-emergent treatment of seeds is probably ineffective due to the hard seed coats and the shallow burial of deposited seed by wind and water-borne sand. Broadcast pre-emergent treatment would also be counter-productive if it resulted in the loss of stabilizing vegetation at low elevations on sandbar fringes (e.g., Yellow nutsedge), which contributes greatly to the longevity of sandbars where nesting occurs at higher elevations.

Some level of on-site mechanical management would likely be needed to inhibit bagpod establishment on SNH. Chopping, followed by direct herbicide application on freshly cut stems performed early in the growing season, would slow site occupation. Multiple applications would be necessary for full control. A second treatment performed after a river stage drawdown for the growing season would probably inhibit growth in most portions of newly formed sandbars, and thereby reduce the rate of vegetation succession by other species. Treatment for control must, however, begin during the first growing season after a sandbar is formed. Annual treatments may be necessary to control new cohorts that germinate from dormant seeds in subsequent years.

Subsequent treatments would also be necessary if sandbars are over-washed and new seeds are deposited, particularly at high elevations that support nesting.

CONCLUSIONS:

As long as the amount or quality of sandbar nesting habitat is considered a potential limiting factor for Least Tern and Piping Plover populations, river managers will be obligated to take action to provide or protect this resource (USFWS 2003, 2005a; USACE 2011). On many regulated rivers, particularly those with large dams, flood frequency has been reduced, and growing season water levels have been stabilized, resulting in conditions that tend to favor vegetation succession on bare river sandbars, the preferred nesting habitat for both listed bird species (Friedman et al. 1998, USFWS 2003, 2005a).

In many cases, altering rule curves to increase flood magnitude or frequency is not possible (USACE 2004). In the absence of the regular disturbance and habitat renewal that frequent flooding provides (Sidle et al. 1992), managers have limited options. One of these is to mechanically create bare nesting sandbars, which is costly, but effective (USACE 2011). In most locations, this technique will have its budgetary limits. Where funds exist for extensive sandbar habitat creation, too much of this activity can have negative human or environmental consequences (USACE 2011).

Previous vegetation management programs have mostly failed to create extensive sandbar nesting habitat for large numbers of Least Terns or Piping Plovers (USDOI 2006, USACE 2011). However, these programs have often focused on starting the vegetation management process after primary succession has occurred, at the point in Figure 10 where costs are highest and the complete removal of all vegetation (which would result in the strongest response from nesting birds) is often infeasible.

The authors propose a different approach to vegetation management that focuses on the prevention of vegetation establishment during periods after floods or habitat creation when bare nesting sandbars are available. This approach is predicated on aggressive response to seedling recruitment as early in the successional sequence as possible. It is also founded in the belief that the prevention of vegetation establishment is far less costly and far more effective than all other options for vegetation removal if succession is not detected and combated immediately.

River management authorities should consider implementing vegetation monitoring programs that include rapid and effective communication feedback between monitoring crews, program managers, water control personnel, and on-the- ground vegetation removal crews. Inaction or delayed action will result in increased overall costs or the complete failure to remove vegetation. Therefore, vegetation management programs need to have the ability to act quickly (e.g., prior permissions from cooperating agencies to send crews out at short notice to remove vegetation, appropriate levels of staffing to respond with many hands after recruitment events, which may not occur every year). This type of administrative flexibility is often difficult for agencies to achieve. Without it, the types of actions that may be necessary to successfully remove vegetation (e.g., have a large field crew respond to a recruitment event within 7-10 days) may be hard to accomplish.

In many locations where sandbar nesting birds are present, existing bird monitoring crews (who visit sandbars regularly during the growing season) could be responsible for the detection of major cottonwood or willow germination events on nesting sandbars. Detecting such events does not require the expertise of a botanist (e.g., Figure 8) and bird monitoring crews are already making focused observations in the areas where bird nesting takes place, which are the areas where germination events are in greatest need of detection to facilitate rapid removal of young seedlings in SNH.

The authors suggest that detection of germination events by bird monitoring crews could be communicated rapidly to a point of contact in the vegetation management program who sits in on weekly meetings with water control. During these meetings, options for using flows to cause the mortality and removal of young seedlings could be discussed within the framework of the myriad factors that water management personnel must consider each week.

In many cases, small increases or decreases in releases from a single dam (e.g., Keystone Dam on the Arkansas River) may be balanced with minor changes to release schedules from other dams that are part of the same integrated reservoir operations. This type of coordination could maximize the amount of early seedling mortality that occurs, which would then minimize the amount of hand or mechanical removal that needs to occur when seedlings survive long enough to establish root systems.

Any vegetation management work that can be done by water manipulation, so long as it does not compromise other water control objectives, will result in cost savings. The use of water manipulation means that vegetation management work will not have to be done in a more costly manner, either by hand by on-the-ground vegetation removal crews or with heavy equipment. The earlier that germination is detected, the smaller that flow increases or decreases will need to be to induce mortality. As plants get larger and root systems become established, water control may not have the flexibility to allow for large enough flow increases or decreases to induce seedling mortality. Again, early detection and feedback are important aspects of water control.

If dedicated vegetation removal crews are not on staff, bird monitoring crews may be employed to remove young seedlings once bird nesting is complete. Bird monitoring crews are typically seasonal employees who could be retained for several extra weeks to participate in hand vegetation removal, since the Least Tern and Piping Plover breeding seasons often end relatively early in the growing season, when hand removal is still possible.

In some locations, bird monitoring crews are large and could make considerable progress towards the removal of first year seedlings across the entire area that they cover during the bird nesting season. In years where recruitment is too extensive, or in areas where large bird monitoring crews are not present, contracts for vegetation removal by local groups, after the birds leave on fall migration, could be set up well in advance, based on feedback on the location and scale of new seedling recruitment from bird monitoring crews across the breeding season.

However this administrative and logistical challenge is met, the aggressive removal of first year plants, as early as possible in the growing season, will be the most effective method for complete removal of vegetation from nesting sandbars, thus prolonging their life as suitable habitat.

When seedlings are not removed before the end of their first growing season and when these young plants survive the winter, their removal may be recommended prior to the next bird nesting season. If plants survive through two growing seasons, their removal via flow management may not be feasible (although this should be considered) and physical removal actions may need to be implemented. Again, contracts for such actions can be set up in advance based on feedback about the extent of vegetation growth from bird monitoring crews. Hand removal will no longer be possible at this point, but physical removal actions during a plant's second growing season may still be possible with hand tools. After the second growing season, heavy equipment will very likely be needed. Each growing season that passes without vegetation removal will add costs, reduce options, and reduce the probability of complete vegetation removal.

Vegetation management programs that focus on vegetation removal after primary succession and after several seasons of growth have occurred will very likely have poor cost-benefit ratios or minimal success (USACE 2011). This outcome from vegetation removal programs will lead to the necessity of costly mechanical habitat creation to sustain regional sandbar nesting habitat in the absence of floods (USACE 2011). Vegetation management programs that dedicate resources to the early detection and removal of young vegetation from newly created sandbars may help to delay, or avoid, this costly action by maintaining adequate SNH to support regional tern populations during periods between large habitat-forming flows.

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